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Effect of highly aerated food on expected satiety

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Abstract

This work shows a practical way to design satiating new products by a real interaction of science and cooking. From the initial idea of the chef, a highly aerated product was designed to prove that the feeling of fullness starts before food is eaten, at the point when the food is just being viewed by the consumer. Mixtures of food-grade silica particles, methylcellulose (MC) and ovalbumin (OA) were used to get better distribution of air and to increase volume. Silica particles at a concentration of 0.3 wt% , mixed with MC (0.5 wt%) and OA (1 wt%) showed higher surface activity and viscoelasticity at the surface than the isolated ingredients. This mixture also showed the highest foam capacity and foam stability compared to the mixtures with none or 0.4 wt% of silica. Highly aerated structures were made by using the mentioned results. To verify the idea of having higher expected satiety with a highly aerated product, consumer study was performed. Subjects reduced their intake when a more-aerated sample was served compared to a less aerated sample.

Keywords: Proteins; Methylcellulose; Silica particles; Foaming properties; Satiety

Introduction

Food industry must have a strong focus on delivering innovation to meet market and consumer trends in health, texture, nutrition and targeted delivery solutions (Berry, 2008). Food developers must remember the following consumer demands: Is it good for me? Is it good for the world? Does it taste good? Does it consider gastronomic culture? Does it give me an extra-value? Chefs could play a key role by inspiring food industry with new developments and by manufacturing healthy and tasty food products. In fact, the creation of healthier, tastier and innovative food is one of the most important concerns of chefs nowadays. From a nutritional point of view, for example, science-based cooking can contribute to provide certain nutrients and other food components, which could confer healthy aspects to the dishes and menus (Navarro et al., 2012).

Common strategies for promoting healthy eating habits are controlling portion size and reducing the energy density of the meal (Hazen, 2007). The mechanisms controlling appetite and hunger are complicated but the study of these mechanisms could help get scientific evidence that could assist consumers in making healthier food choices. There are two different processes related to food intake. Firstly, satiation, that refers to the act of stopping food intake, an immediate reaction to the ingestion of food. During satiation, it seems clear that sensory (taste, volume, texture…) and cognitive factors will play an important role (De Graaf, 2012). Secondly, satiety, that refers to motivations to eat in between meals (Blundell et al., 2010), is body's response to the availability of nutrients from food that have been already digested and processed. From those close but different concepts, it has been reported that deficiencies in satiation seem to show more connections to obesity and binge eating than actual satiety (Kissileff, 1995; Spiegel et al., 1989).

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Therefore, enhancing satiation could restrict the daily food intake and the desire of overeating, contributing to body weight control (Hoad et al., 2004). Considering that satiation is partially governed by sensory factors (Blundell et al., 2010), it would be interesting to develop a product focused on the satiating effect of sensory perception, such as the visual factor. Consumer's sight influences the quantity of consumption, leading them to be less influenced by physiological signals of satiation. Wansink (2005) showed that manipulating visual signals of how much is eaten influences further intake: *people use their eyes to count calories and not their stomachs*.

There are many methods for the development of products related to this effect (satiation), which are based on lowering caloric density or modifying structure. For instance: the use of non-caloric ingredients, immobilizing high quantities of water and incorporating air as small dispersed bubbles (Zúñiga and Aguilera, 2008). Recent published research has highlighted the link between applied material characteristics like viscosity or gel performance of polysaccharides in food matrices and the effect of gastric emptying and satiety (Knarr et al., 2012). Methylcellulose (MC), for example, could be a good alternative, because it is a modified cellulose fiber that produces viscous solutions in the gastrointestinal tract. Furthermore, at the 244th National Meeting & Exposition of the American Chemical Society, a new product was presented based on modified methylcellulose that could present satiety properties (Huettermann, 2012).

Fixing air in food could be another alternative to design satiating products. In recent years, new aerated foods from the market are perceived as lighter in terms of calories, thus satisfying consumer needs. However, introducing a gas phase into a food matrix not only affects its texture and firmness making the product lighter, but also changes the appearance, color and mouth-feel (Campbell and Mougeot, 1999). So, it is essential to revise this aspect because these products are not only consumed for health purposes, but also for enjoyment. Aerated foods may provide a sense of fullness in comparison to the non-aerated food. There is some evidence that food intake is influenced by both the weight and volume of foods. It has been reported that increasing the air content may be an effective strategy to reduce energy intake from energy-dense products, like snacks (Osterholt et al., 2007). In this study, consumers ate 21% less weight and energy of the more-aerated snack than the less-aerated snack. This work presented the product with the same volume for both cases, so it is impossible to know whether consumers expected to be satiated before eating the product, just by sight signals. To the best of our knowledge, there is no literature at all describing the relation between expected satiety (from initially visual observation) and product volume.

The main objective of the present study was to design a significantly high-aerated product. This scientific study, together with chefs' gastronomic knowledge, would be used to fix the initially aerated structure, to get better distribution of air and increase volume, in order to check the perception of being full before eating. It was then hypothesized that the most-aerated product might give higher expected satiety than the less-aerated product.

Materials and methods

Materials

Methyl cellulose (Methocel Premium A15, mean molecular weight 14 kDa, methyl substitution between 27.5% and 31.5%) was obtained from The Dow Chemical Company (Midland, TX). Albumin from chicken egg white (A-5504) was purchased from Sigma-Aldrich (98%) and fumed synthetic amorphous silica AEROSIL® was purchased from Evonik Industries.

Two methodologies were used to get samples with different aeration. Two recipes were whipped at different speed to get structures of diverse volumes. The first one, the high aerated product (HA) was formed by pasteurized egg white, methyl cellulose (MC), amorphous silica and maltodextrin, which helped in the reinforcement of the foam structure. This dough was whipped in a Kitchen Aid Fagor® for 5 min at maximum speed. The second sample, the low aerated product (LA) was made just by pasteurized egg white, methyl cellulose and maltodextrin, and was whipped at the 4th speed for 20 min. After whipping, visually different samples were obtained with both methodologies. The final presentation of the dish ends with 15 g of each type of foam put in a Pirex® bowl.

Surface tension

Surface tensions at the air–water interface of protein solutions were measured by using an FTA200 pulsating drop tensiometer (First Ten Ångstroms, USA). The capillary drop was formed within an environmental chamber at room temperature, in which standing water increased the relative humidity to minimize drying effects. All measurements were made at room temperature (≈ 20 °C). Surface tension was monitored at room temperature for 30 min.

Surface rheology

Surface shear rheological measurements were carried out to study the mechanical and flow properties of adsorbed layers at fluid interfaces, which were sensitive to surface structure and composition (Ridout et al., 2004). Experiments at the air–water interface were made using a stress controlled rheometer, AR2000 Advanced Rheometer (TA Instruments) and an aluminum bicone (diameter 60 mm, angle cone 4:59:13) as measuring geometry. The surface rheological response in 50 mL solution was tested by oscillation mode within the range of linear viscoelastic region at a frequency and strain of 0.1 Hz and 0.014, respectively. Measurements were performed at room temperature for 30 min.

Foaming properties

Foam production was achieved by using a Foamscan TM apparatus (Teclis-ITConcept, Longessaigne, France), whose principle is to foam a 10 mL solution by gas sparging (N_2) through a porous glass frit (flow of gas: 45 mL min^{-1}; porosity 16–40 μm). The amount of liquid incorporated in the foam and the foam homogeneity are followed by measuring the conductance in the cuvette containing the liquid and at different heights in the column by means of electrodes. Bubbling was stopped after 80 s. Drainage of the foam was followed via conductivity measurements at different heights of the foam column. A pair of electrodes at the bottom of the column was used for measuring the quantity of liquid that was not in the foam, while the volume of liquid in the foam was measured by conductimetry. After turning off the gas, the foam height was read from the calibrated markings on the column. The time for the collapse of the foam to half its initial value was measured to express the foam stability. Two parameters were determined as a measure of foaming capacity. The overall foaming capacity (FC) was determined by measuring the maximum volume reached by the foam at the end of sparging. Foam stability was characterized by half-life of foam $t_{1/2}$ (s), the time for draining half of the initial volume of the foam (Eq. (1))

$$t_{1/2} = (k_2 V_o)^{-1} \quad (1)$$

Consumer study

Subjects

There were **25 subjects** (M/F: 6/9, age: 35 ± 6.0 and BMI: 22.9 ± 2.7 kg/m^2) who were students or employees at the Azti-Tecnalia Food Research Institute. Participants completed an inclusion questionnaire, in which body weight and height were reported. Exclusion criteria were: lack of appetite, following an energy-restricted diet or change in body weight > 5 kg during the last 2 months, stomach or bowel diseases, diabetes, thyroid disease or any other endocrine disorder and hypersensitivity for food products under study. Subjects were unaware of the aim of the research.

Procedure and experimental design

Regarding the consumer behavior, subjects were instructed to consume the same breakfast and not eat anything else and only drink water or weak tea, 2 h before lunch started. Moreover, they were asked to refrain from drinking 1 h before the test started. To make sure that the subjects would eat till they felt satiated; they were instructed not to eat 1 h after the test. Each subject was seated on a separate table with a sample bowl. During break (10.30 h–11.00 h), subjects had free access to water. Subjects had to indicate the hour when they started and when they finished consumption of the samples, so that the eating time was recorded. They were instructed to terminate consumption when they felt they had enough. The mean initial temperature of the aerated product was 20 °C.

Fig. 1. High-aerated and low-aerated samples for sensory studies. Subjects were served a sample of 15 g.

We manipulated two stages: (1) expected satiation and (2) the acceptability and the oral exposure time at the end of the oral eating process.

In the first stage, participants rated the expected satiation on a 100 mm line scale anchored from "not full at all" to "extremely full" to the question "how filling would you expect this portion of food to be?". This procedure was repeated for the different samples and presentation order was randomized across participants. Average expected satiation values were calculated for all structure items by averaging across participants.

In the second stage, oral perception at the end of the oral eating process, subjects were served a sample of 15 g to rate after tasting the sample (Fig. 1). When they finished the product, it was rated for overall acceptability according to the scale VAS.

For each individual, two samples were analyzed in two different sessions with a week's gap between them. Twelve consumers were invited to evaluate the LA sample and the rest of the group evaluated the HA sample in the first sessions. The same occurred in the second session, but in reverse.

Data analysis

Statistical analysis was carried out with the R 2.14.0 Programme (R Development Core Team), with the packages Commander, Agricolae, Sensominer and Factominer. One way Analysis of Variance (ANOVA) was employed to check for individual differences between two samples.

Results and discussion

Designing an aerated food product for the restaurant

Our starting point was that an aerated product could potentially achieve a reduction in caloric density and it could induce satiety by making novel gastronomic structures.

Another important issue for the chef was to create, literally, the sensation of lightness in a dish.

The creation of foams essentially requires the formation of fine bubbles. The main factor controlling droplet size is the interfacial tension (Wilde, 2000). Apart from the considerable interest in the effects of silica on human health (Martin, 2007), these partially hydrophobic particles are also known to

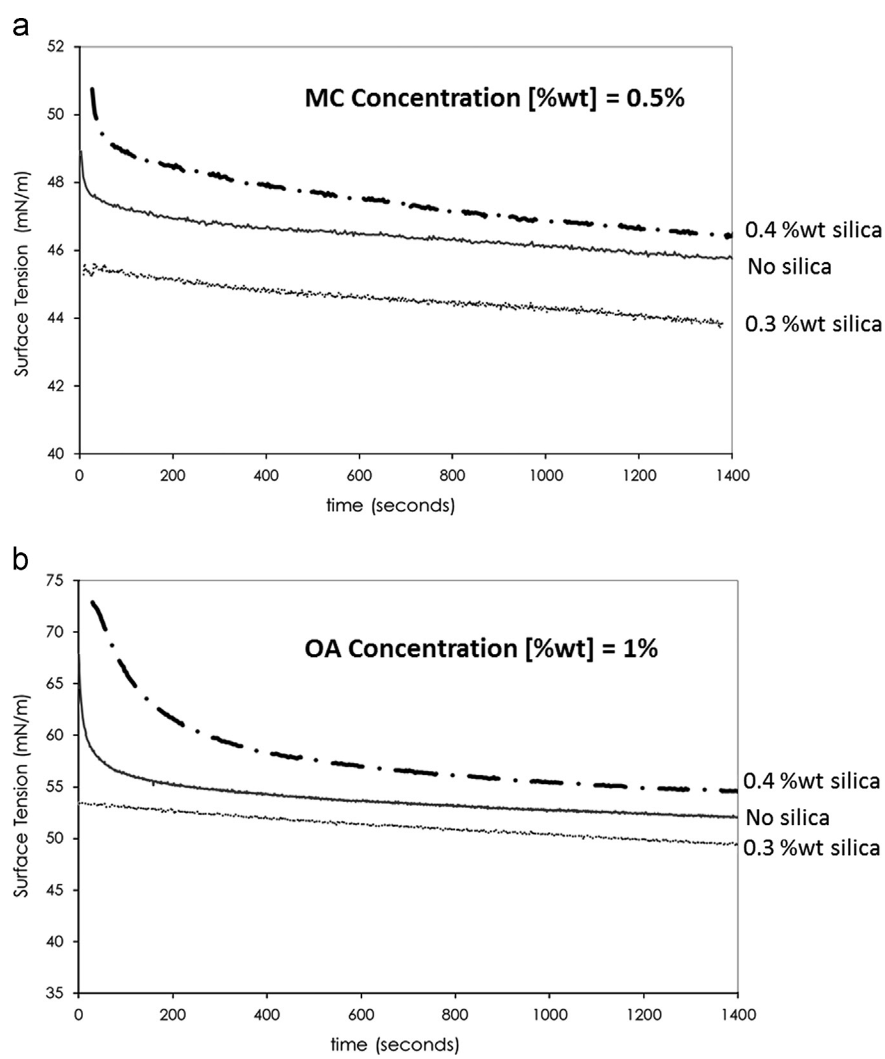

Fig. 2. Effect of silica concentration on the surface tension (taken at 30 min) versus time as measured by the pendant drop technique for (a) constant concentration of methylcellulose (MC) (0.5 wt%) and (b) constant concentration of ovalbumin (OA) (1 wt%).

stabilize the interface even in the absence of any added surfactant (Aveyard et al., 2003), and extend storage stability (Castro et al., 2006). The development of surface tension in time, upon creation at the air–water interface of two different samples, was studied by using the pendant drop technique using an essential protein solution (OA) and a surface active polysaccharide (MC). The surface tension of MC and OA solutions are shown in Fig. 2a and b, respectively. Isolated MC samples lowered the surface tension more rapidly than isolated OA even with half the concentration. Adding 0.3 wt% of silica particles in a constant concentration of MC (0.5 wt%) and OA (1 wt%) seemed to lower the surface tension more rapidly than isolated ingredients without silica particles whereas at 0.4% of silica the system was less surface-active (Fig. 2).

The surface rheology of adsorbed amphiphilic compounds or even particles has long been known to be important for the stabilization of foams. The impact of silica particles on the surface rheological properties of OA and MC solutions was then investigated. Fig. 3 shows the shear elastic modulus of 0.5 wt% and 1 wt% solutions of MC and OA measured over a period of 30 min. It can be observed that G' at the presence of 0.3% silica particles increased more rapidly than isolated ingredients at short times followed by slow increase at longer times. The increase in surface rheology with time can be considered to be a result of silica particles adsorption at the interface, forming a much stronger interface. This synergy might be attributed to the ability of MC and OA to increase the silica particle contact angle on adsorption (Hunter et al., 2008). However, MC and OA with 0.4 wt% of silica showed less elastic interfaces than isolated ingredients and mixtures with 0.3% of silica. This increased silica concentration may lead to site competition between the particles and surface active molecules. Foaming properties (Fig. 4) seemed strongly correlated to the rate of adsorption at the air–water interface (Fig. 2) and thereby to the decrease of surface tension, giving a higher foaming capacity up to 0.3% of silica particles for both mixtures of MC and OA. The higher viscoelastic properties (Fig. 3), once again for both mixtures of MC and OA and up to 0.3% of silica particles, resist the shear stress resulting from liquid drainage and improve the foamability and foam stability under these conditions. A higher viscosity in the aqueous solution could retard the drainage in the foam. This does not

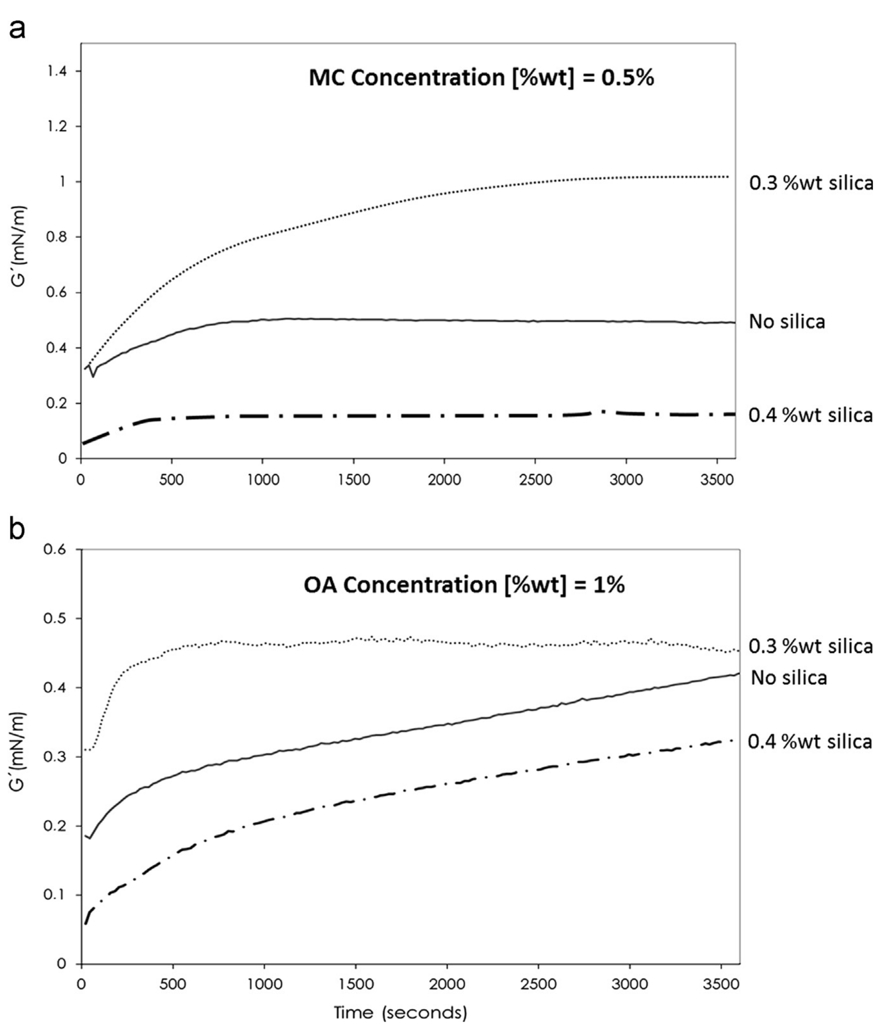

Fig. 3. Effect of silica concentration on the surface shear elastic modulus versus time for (a) constant concentration of methylcellulose (MC) (0.5 wt%) and (b) constant concentration of ovalbumin (OA) (1 wt%).

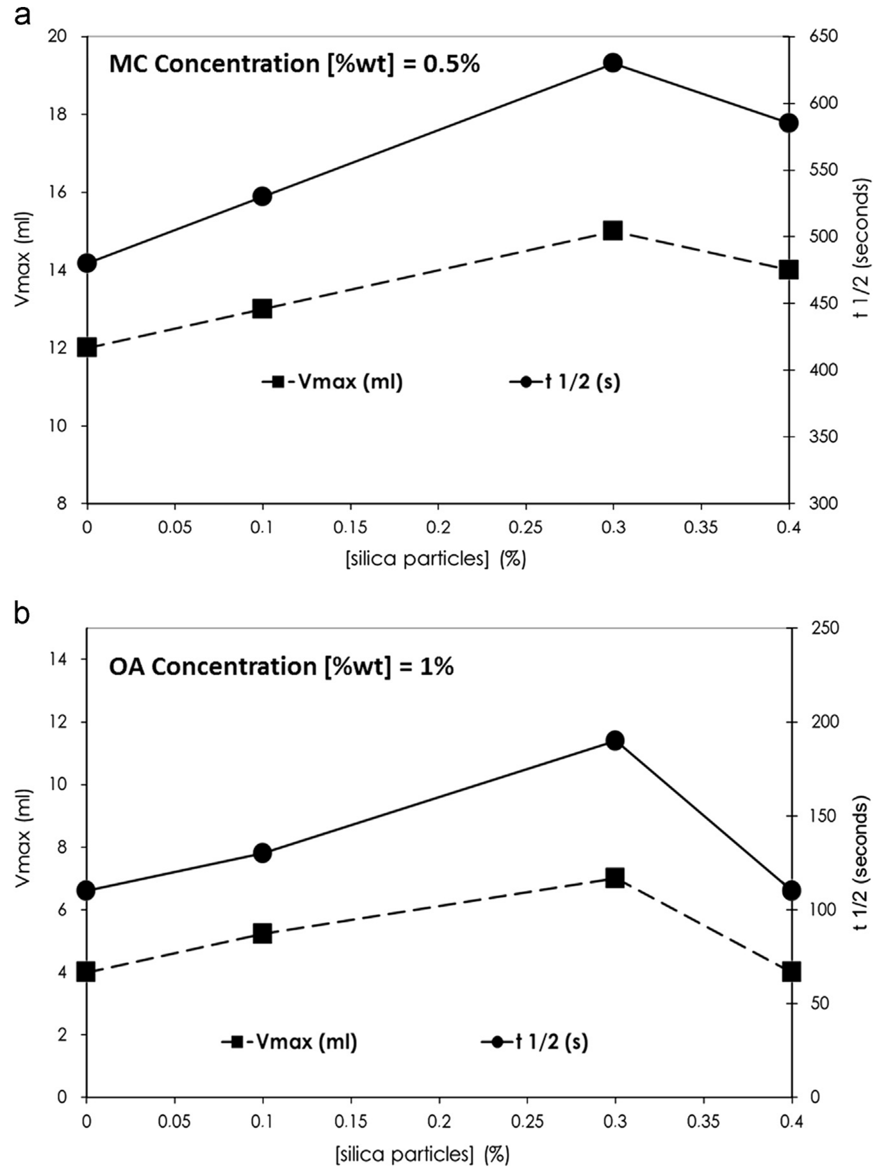

Fig. 4. Effect of silica concentration on foaming capacity and foaming stability for (a) constant concentration of methylcellulose (MC) (0.5 wt%) and (b) constant concentration of ovalbumin (OA) (1 wt%).

seem to be the case because of the small differences in viscosity of the solutions made by isolated OA and MC compared to silica–OA–MC solutions (data not shown). Silica nanoparticles seem to provide stability in foams, especially related to disproportionation and bubble shrinkage thus giving much better results than with isolated proteins (Dickinson, 2010).

By using the knowledge acquired from the studies described above, the recipe was formed by ovoalbumin, methylcellulose and amorphous silica which helped in the reinforcement of the foam structure. Additionally, sugar was replaced by a syrup made by maltodextrin and water, which was inserted into the whipped mixture. Finally, the aerated structure was left in an oven at 55 °C to obtain the final structure. The final presentation of the dish includes different varieties of berries and only 2 g of the aerated structure (Fig. 5).

Checking the relation between aeration degree and expected feeling of fullness

Since the aim of the work is to assess the influence of aeration type on the intake of different samples, one important aspect was to know the influence of the intake, the oral exposure time and the acceptability about high and low aeration.

Aeration degree of the product had a significant effect on the intake ($p=0.03$; Table 1). On the other hand, there was no significant effect either on the oral exposure time ($p=0.63$; Table 1) or on the acceptability ($p=0.24$; Table 1). However, the results should still be taken with care , since within the absolute error margin, the intake falls in the same window.

According to Hogenkamp et al. (2011), the effect of satiety expectations on actual intake may be important to better

Fig. 5. An aerated product that induces a sense of fullness based on the principle that satiation begins when you first look at the product: *Evoking a spring morning*. Photos by Jose Luis Lopez de Zubiria-Mugaritz.

Table 1
Results of the means, standard deviation and one way ANOVA (aeration) of the intake, oral exposure time, acceptability and expected satiety.

Variables	HA	LA	F	p-Value
Intake (g)	6.74 ± 4.50	9.32 ± 3.59	5.03	0.03
Time intake (min)	2.50 ± 1.08	2.60 ± 1.28	0.22	0.63
Acceptability (mm)	48.40 ± 20.14	53.60 ± 18.00	0.92	0.34
Expected satiety (mm)	56.12 ± 17.74	44.52 ± 19.23	4.91	0.03

understand our regulation of food intake. The ratio of expected satiety of high and low aeration was 56.12 mm and 44.52 mm (scale from 0 at 100 mm) respectively. This means that the aeration degree of the product had a significant effect on the expectation ($p = 0.03$; Table 1). The study clearly shows that a difference in the air content of a food affected the volume consumed when two types of samples were served and consumed *ad libitum* intake with same weight and calories.

Conclusions

Silica particles at a specific concentration and mixed with ovalbumin and methylcellulose showed higher surface activity and more viscoelasticity at the surface than the isolated ingredients. The highest foam capacity and foam stability were obtained by adding 0.3 wt% of silica particles in a constant concentration of MC (0.5 wt%) and OA (1 wt%) which is related to the studied interfacial properties.

This study permitted to produce highly aerated structures to arrive at the design of new dishes mainly focused on producing high levels of expected satiety.

Subjects reduced their intake when a more-aerated sample was served. These results confirm and extend the findings from previous studies indicating that the amount of air incorporated into food can affect the energy intake (Rolls et al., 2000; Osterholt et al., 2007). These results open an interesting and promising path for the design of food for wellness. Further research on satiety and satiation should include chefs for a better understanding of these complex mechanisms.

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